DRAINAGE INVESTIGATIONS BY THE UNITED STATES DEPARTMENT OF AGRICULTURE

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The first definite recognition by Congress of drainage work as distinct from irrigation was in 1904 when the Department of Agriculture appropriation bill for the fiscal year 1905 carried an item of $67,500 for "Irrigation and Drainage Investigations." Similarly for the four succeeding years a joint appropriation was made. From 1910 to 1924 inclusive, separate appropriations were made for irrigation and for drainage. For the fiscal year 1925 the plan of joint appropriations was resumed, funds for irrigation, drainage, farm structures, and farm mechanical equipment being appropriated under the single item "Agricultural Engineering." The amounts of funds made available for drainage for each year are as follows:

1905	$67,500 1/	1921	$53,760
1906	74,200 1/	1922	73,760
1907	122,200 1/	1923	72,260
1908	150,000 1/	1924	72,260
1909	150,000 1/	1925	83,000
1910	81,160	1926	86,000
1911	78,860	1927	74,900
1912	100,000	1928	67,500
1913	100,000	1929	63,800
1914	97,600	1930	82,500
1915	96,280	1931	75,000
1916	96,280	1932	80,920
1917	94,720	1933	74,300
1918	93,760	1934	43,400
1919	73,760	1935	44,050
1920	73,760	1936	45,047

1/ Under one appropriation for irrigation and drainage.

The first drainage work was carried on by the Division of Irrigation and Drainage Investigations in the Office of Experiment Stations of the Department. Later irrigation and drainage work were separated and a Division of Drainage Investigations was organized in the Office of Experiment Stations to handle the drainage work. Until 1912 Mr. C.G. Elliot, a former President of the Illinois Society of Engineers, was in charge of the drainage work. In 1912 Mr. Elliot resigned and was followed as Chief of Drainage Investigations by Mr. S. H. McCrory. In 1915 Drainage Investigations and Irrigation Investigations were transferred from the office of Experiment Stations to the Bureau of Public Roads, together with the farm machinery and the farm buildings studies from the office of Farm Management.

In 1920 the Division of Drainage Investigations, the Division of Irrigation Investigations and the Division of Rural Engineering, all of the Bureau of Public Roads, were combined to form the Division of Agricultural Engineering with Mr. McCrory as Chief, and in 1931 legislation was passed by Congress changing the status of this Division to that of an independent Bureau in the Department with a division to handle drainage investigations.

EARLY WORK

The first drainage work carried on by the Department was confined largely to examinations, surveys and reports made in an attempt to assist groups of landowners who desired to reclaim lands that were swamp, or subject to overflow, by advising with regard to the drainage works required and the cost of drainage. To that end, prior to 1920, examinations and surveys were made for the reclamation or improvement of more than 11,000,000 acres. The approximate areas covered by states are as follows:

State	Acres	State	Acres
New York	10,440	West Virginia	6,000
New Jersey	10,000	North Carolina	573,264
		South Carolina	247,436
Indiana	500,000	Georgia	58,335
Illinois	128,000	Florida	1,850,000
Michigan	113,900		
		Kentucky	109,760
Minnesota	216,000	Alabama	23,000
Iowa	84,770	Mississippi	824,346
Missouri	285,000		
North Dakota	1,588,400	Arkansas	1,933,684
South Dakota	82,370	Louisiana	1,582,000
Nebraska	180,100	Oklahoma	101,500
Kansas	244,340	Texas	530,670
Delaware	6,625	Idaho	40,000
Maryland	7,385	Washington	16,500
Virginia	39,320	Total	11,393,145

The reports for some of the projects have only outlined the general features of the works to be constructed, showing tentative locations and sizes and estimating costs from approximate data. In a great many instances, however, accurate plans and estimates were prepared from engineering survey, many of which have been used by the District's engineers in their reports to the district authorities. In the making of the surveys, the districts cooperated by bearing a considerable part of the cost. The reports of thirteen representative projects have been printed as bulletins by the Department. When this type of work was started, large scale drainage by organized drainage districts was a comparatively new field of activity over a large part of the country, and it was felt that the projects assisted by the Department would serve as valuable demonstrations of drainage work. Beginning about 1915 it was felt that drainage was well enough established and that there were a sufficient number of experienced private engineers in the drainage field to make such work unnecessary and since that time the work of the Department has been devoted primarily to technical research investigations in the drainage field.

RUN-OFF INVESTIGATIONS

One requisite for the economical design of drainage improvements is reliable information relative to the run-off that must be provided for. To obtain such information the Department has over a period of years conducted measurements of flow in natural and artificial channels in a considerable number of typical situations, and obtained records of the various conditions affecting the maximum rate and the total amount of run-off. These quantities depend not only upon the amount of rain and size of area drained, but also upon the distribution of rainfall, temperature, topography, soil, vegetation and natural storage. Continuous records for several years have been secured at locations in Iowa, Missouri, Louisiana, Tennessee, Mississippi, Arkansas, Florida, Illinois, Indiana, and Ohio. At the present time, due to shortage of funds, the work is limited to two small watersheds in the vicinity of Iowa City and to a number of areas in the Everglades section of Florida. The results secured when studied in connection with published rainfall data are extremely helpful in planning drainage ditches in other regions.

HYDRAULIC FACTORS OF DRAINAGE CHANNELS

The hydraulic factors of drainage channels are studied in conjunction with the run-off investigations. On selected sections of typical ditches and natural streams, accurate measurements are made of the dimensions of the stream, the slope of the water, and rate of discharge, with careful description of the roughness of channel perimeter, the uniformity of cross section, and the snags and growing vegetation obstructing flow. This study, the results of which have been published in bulletin form, has resulted in more reliable determinations of the coefficients in hydraulic formulas, so that the sizes of proposed ditches and the capacities of

existing waterways can be computed with more certainty. It also has emphasized the value of keeping waterways clear of weeds and other obstructions in order to maintain their efficiency.

The capacities of drains of clay and concrete tile and of corrugated metal pipe have been studied by laboratory methods, and a formula has been devised for computing the flow in such conduits up to twelve inches in diameter. These results have also been made available in bulletin form.

A study of flow of water through culverts conducted at the hydraulic laboratory of the University of Iowa and in cooperation with that institution developed interesting information, particularly relating to the most desirable form of wing walls and other conditions at entrance and exit. The work showed that rounding the ends at entrance increased the discharge, and that clay and concrete pipe culverts with water entering the bell end of the pipe have greater capacity than corrugated metal pipe.

At the same laboratory, cooperative investigations relating to the effect of bridge piers and pile trestles in obstructing the flow of water in streams were carried on over a period of years. Some 2,600 tests on large scale pier and trestle models were made under a more extensive range of conditions than had hitherto been attempted. The most efficient shapes of piers for different conditions of flow and the proper coefficients for the standard formulas have been determined as a result of this work. The report covering the work on culverts has been published as a bulletin of the cooperating institution, the University of Iowa, while the work on pile trestles and bridge piers has been published as technical bulletins of the Department of Agriculture.

Laboratory work on the determination of losses in pipe bends of various shapes in pipes six inches in diameter has been completed and an analysis of the data obtained is now under way. It has been found that bends can be used as flow meters, because for any given flow there exists a constant differential of pressure between the outside and inside of the bend. The loss of head in the bends varies from about twenty to one hundred percent of the maximum value, depending on the cross-sectional distribution of the velocity of the water in entering the bend.

RAINFALL INTENSITY-FREQUENCY DATA

The frequency with which high precipitations of short duration have occurred in different sections of the United States have been determined by the Division of Drainage as a project of the Civil Works Administration. Available data relating to excessive precipitations at 206 of the Weather Bureau Stations in the United States have been summarized. In all, 28,077 rainstorms were studied. Charts have been prepared and included in the publication reporting the project showing, principally by means of isohyetals, the maximum amounts of rainfall in periods of 5, 10, 15 and 30 minutes and of 1 and 2 hours that may be expected to recur on an average of once in 2, 5, 10, 25, 50 and 100 years, and the amounts of rainfall in 4, 8, 16 and 24 hours that may be expected once in 5, 10, 25, 50 and 100 years. No comparable compilation and analysis of rainfall data has ever been made. The information is valuable to engineers in the design of works for farm-land drainage, soil erosion control, culverts and bridges, flood control and municipal drainage.

PUMPING FOR DRAINAGE

Extended investigations have been made of drainage pumping plants in Illinois, Iowa, and southern Louisiana. Drainage pumping ordinarily is characterized by large quantities of water handled, intermittent opera-

tion, and low lifts or extreme variations in lift. Mechanical tests have been made, in cooperation with the drainage districts or the manufacturers of the machinery, to determine the comparative efficiencies of different types of engines, motors and pumps, under the varying conditions, and of different arrangements of piping. The investigations have covered costs of operation and maintenance as well as of original installation, and the relation of these costs to quantity of water pumped, height of lift, efficiency of mechanical equipment and conditions of operation. The studies have shown that the location of the plant with respect to transportation facilities may affect the choice of power or fuel to be used; that the size and cost of machinery may be reduced by providing reservoir capacity in the ditches; that a large quantity of drainage from upland usually can be diverted around the district more cheaply than it can be pumped out, and that the ultimate economy of high mechanical efficiency depends greatly upon the total hours of pumping per year and the waste of power in starting and stopping. The results have been published in bulletin form and made available to the public.

CONSTRUCTION AND MAINTENANCE OF DRAINAGE WORKS

Investigations have been made of the methods and the equipment used in constructing levees and ditches. Data have been collected concerning the character of work performed by the various types of excavating machines, the kinds of work to which each type is adapted, and the cost of construction by different methods under different conditions of soil, water, timber growth, and size of ditch or levee. The information has assisted manufacturers, contractors, engineers and drainage district officials in perfecting and selecting machinery and in reducing cost of drainage. Methods and machinery for the installation of tile drains also have been studied

and the results published.

Information has been collected and disseminated relative to sedimentation and erosion in drainage ditches, methods and cost of clearing ditches of silt and vegetation, and the prevention of injury to levees.

Forms of gates, sluices, inlets, drops and silt basins for open ditches and tile drains have been studied from the standpoint of operation and construction and the results have been made available by publication.

The sizes and dimensions of dikes for reclaiming tidal lands have been investigated, with the sizes and arrangements of ditches and tide gates, for various ranges of tide and elevations of land. The methods of constructing and protecting the works were studied, and of the subsequent treatment of the reclaimed land.

The Department has pioneered in investigations to develop methods of making concrete tile that can safely be used in alkali and acid soils. The work has been under way for some twenty-five years. Laboratory studies of the deterioration of concrete tile in Western alkali soils early established the fact that various sulphates were the principal cause of injury. In cooperation with the University of Minnesota and the State Department of Conservation, an extended series of laboratory and field experiments relating to concrete-alkali and the effect of soil acids and frost on drain tile have been under way for the past fifteen years. Under this project more than 30,000 concrete samples of various types have been exposed to sulphate waters in Medicine Lake, South Dakota. A progress report on the work was published in 1933. It has been determined that only cements above the average in resistance should be used in concrete to

be installed where sulphates are present. Recent studies have devised a test routine for accurately determining the resistance of a portland cement to attack by magnesium and sodium sulphates, the alkalies most common in the subsoil of Minnesota and states further west. It has been found that the most highly resistant standard portland cements will last up to ten times as long as cements of low resistance, under idential conditions of exposure to these chemical compounds. It has been determined also that sulphate resistance of the concrete can be increased considerably by addition of calcium chloride in proper proportion when the concrete is being mixed, if followed by curing of the concrete in moist air at temperatures of 100° to 150° F. It is now common practice at many commercial tile plants to cure their products within this range of temperatures, and use of the calcium chloride admixture would increase the cost of the tile but slightly - about one-fifth of a cent per foot for 6-inch tile.

Studies in connection with clay tile have made it possible to predict with some degree of accuracy, from standard absorption tests, the frost resistance of tile. This development has greatly simplified the testing of such tile and is having an effect in bringing about a general improvement in the quality of the clay tile sold in regions where the tests have been made.

Studies of the drainage of peat and muck soils in Louisiana and Florida have shown that drainage and cultivation result in compacting the soil and lowering the ground surface, the subsistence in many places being as much as three feet in the first three or four years, but the rate decreases with time. In a number of areas in Florida where the original depth of peat ranged from seven to ten feet, the total subsidence in the first twenty years following drainage has been approximately five feet.

At the Everglades Station the total subsidence during the past eight years on soil continuously in cultivation has averaged 1 1/2 inches per year. Rates at two other places have averaged somewhat higher. Lowering of the surface increases the cost of drainage by necessitating deepening of the drains, and by increasing the pumping costs where the drainage waters must be pumped. Where the soil is shallow over rock, subsidence may in time reduce the cultivable depth to such a degree as to greatly limit crop production and even render the land unfit for agriculture.

DRAINAGE DISTRICT ORGANIZATION, ADMINISTRATION AND DEVELOPMENT.

When the Department's drainage investigations were initiated, most states had laws authorizing the establishment of drainage districts or public ditches on the initiative of the landowners, yet very little drainage had been accomplished under them except in the north central states. The laws of most states were not suited to the reclamation of large tracts practically undeveloped and, without drainage, mostly unfit for cultivation.

After a study of the laws under which effective drainage organizations had been established, in collaboration with landowners and others interested, new legislation was drafted for other states to provide a practical form of organization with power to levy and collect assessments for drainage and to issue bonds that would be a valid lien on the land. Since the assistance given in formulating the North Carolina drainage district law of 1909, nearly all the states, including those in the irrigated region, have enacted new or amended laws along the general lines recommended by this department. A study of drainage assessments has been made, that publication of the information collected might assist district officials in equitably apportioning the cost and prevent misunderstandings which are the principal cause of litigation.

Development of most of the swamp and overflowed land involves clearing the land of stumps and second-growth timber, which may cost more than drainage. Data have been gathered as to methods and cost of such clearing. Studies have been undertaken for determining the further work and cost of developing such land into profitable farms, and the extent and character of land that is available for settlement. Estimates have been compiled from the most complete data available, which indicates that in the United States there are now approximately 113,000,000 acres in need of drainage outlet facilities that must be obtained by community enterprise, including about 91,000,000 acres that are unfit for cultivation because of lack of drainage. There are now in excess of 70,000,000 acres in drainage districts for which the drainage works are wholly or partly completed.

DRAINAGE OF IRRIGATED LANDS

The first drainage studies related to the drainage of irrigated lands and were begun in 1902 under the appropriation for irrigation investigations in California and Colorado. As the damage by waterlogging and the concentration of alkali increased, the studies of groundwater movement and of methods of intercepting seepage, lowering the water table, and removing alkali were broadened, and by 1910 drainage engineers of the Department were stationed in several of the irrigated states to study conditions and assist landowners. In cooperation with individuals and groups of landowners and with state institutions, experimental drainage systems were early installed at Fresno, California, at Sunnyside, Washington, at several locations in Utah, and in other states. The studies furnished important data concerning proper depth and size of drains and concerning location of drains with respect to topography, soil stratification and irrigation works.

Community effort being essential in most instances, aid was given in framing drainage district laws suited to the artificial conditions caused by irrigation. Encouragement and advice were given to landowners in the organization of such enterprises, and in designing and financing the district drainage systems. Thousands of acres have been restored to productivity and an impetus given to reclamation of the remaining area requiring drainage as a result of irrigation.

Sir William Wilcox, the noted British Engineer, during his visit to this country some twenty-five years ago stated that the early work on the drainage of irrigated land, carried on under the leadership of Mr. Elliot, was the only new thing he had encountered in the irrigation field. There is no doubt but that it has been a decided contribution toward placing irrigation agriculture on a permanent basis.

TILE DRAINAGE

Experimental systems of tile drainage have been installed in cooperation with farm owners, in different regions and types of soil, and the fluctuation of the groundwater table in drained and undrained portions of the fields have been observed by means of test wells and related to accurate records of the rainfall upon the farms. These investigations have been valuable in determining the proper depth and spacing of drains to secure effective drainage for the least cost. The data have been used in drainage bulletins issued by this Department and by agricultural colleges and other state institutions.

SOIL EROSION CONTROL

The first experimental work by the Department of Agriculture in control of soil washing was started in 1903, by Drainage Investigations of the Office of Experiment Stations, the predecessor of the present Division of Drainage. The experiment, located on a farm in Georgia, consisted of

laying tile drains at the foot of a slope where serious gullying had developed, for the purpose of giving the soil greater stability by carrying off the surplus water. After the drains were laid the gullies were filled and the field planted. The experiment was continued for two or three years; the results indicated that tile drains are an aid in controlling erosion under certain conditions.

In 1915 a comprehensive field investigation was started to determine the most effective engineering methods of controlling soil erosion. As a result of this work the first comprehensive treatment of the subject was issued in 1917 as Department Bulletin 512 entitled "Prevention of the Erosion of Farm Lands by Terracing." This bulletin described the various types of terraces and their construction, stressed the advantages of the broad-base terrace, outlined methods of designing terrace systems and discussed briefly the use of vegetation to control erosion. A farmers' bulletin was issued in 1918 giving in non-technical terms rules for terracing. Then, in 1922 an additional farmers' bulletin was issued entitled "Gullies - How to Control and Reclaim Them," which describes the construction and use of dams to check enlargement of gullies and cause filling of them by deposition of silt carried by the water flowing through them. These bulletins have been widely distributed and have been used as a guide in construction of terraces and soil-saving dams on over 20,000,000 acres of land during the past twenty years. In April 1935, this phase of the work of the Division of Drainage was transferred to the newly organized Soil Conservation Service.

PRESENT WORK

Drainage work under way at the present time is confined primarily to research projects. Cooperative investigations with the Minnesota Department of Conservation and the University of Minnesota are being con-

tinued to determine the factors that influence the permanency of underdrains, because of failures of the structural material used as the result of chemical and frost action.

At the hydraulic laboratory of the University of Iowa cooperative investigations are under way with that institution relating to the flow of water around bends. Investigations are planned to develop the theory of the hydraulic jump on sloping floors. Such information would be of much value in the design of spillways, and the construction of structures for discharging lateral drains into main outlet channels.

In Florida, studies are being made to determine the optimum depth of drainage for different crops in the peat and muck soils of that region, and the means and cost of maintaining these depths. There are more than 3,400,000 acres of peat and muck soils in Florida, mostly in the Everglades section. A great part of these lands, to be suitable for cultivated crops, must be protected by levees against overflow and be drained by pumping. Maintenance of the groundwater table at a fairly uniform depth is more important in these than in the finer loam and clay soils.

In southern Louisiana an investigation is underway to determine the most advantageous depth and spacing of drains for sugar cane land, and the effect of drainage upon yield of cane and sugar. The work will have to be continued for several years before definite conclusions can be reached. To date, good surface drainage and underdrainage 2-1/2 to 3 feet deep has given as good results as deeper drainage.

Run-off investigations are being continued on two small watersheds in Iowa. This phase of the work has been limited due to lack of funds and will be increased if additional funds are made available.

In northern Minnesota studies are being made to determine the relation of the groundwater table to drainage in that region. It is expected that the data collected will indicate whether or not the groundwater table has been materially affected by the drainage works so far constructed, or whether the fluctuations are due primarily to deficiency in rainfall.

In the spring of 1935 the Director of Emergency Conservation Work assigned forty-seven Civilian Conservation Corps Camps to the Bureau of Agricultural Engineering to work upon the maintenance of drainage improvements in organized drainage enterprises. The work of these camps is being covered by another paper to be delivered before this meeting.

CONCLUSION

In the field of drainage, we should recognize that at the present time there is an apparent over-production of agricultural products; that we have more land under cultivation than is necessary or advisable under existing conditions. It therefore seems logical that those really interested in the welfare of agriculture should oppose the undertaking of new drainage improvements that will bring additional land under the plow at this time. This does not mean, however, that there is at the present time no need for drainage work. We are all acquainted with farms having pot holes or sloughs that divide them into irregular fields difficult to farm to best advantage. In many instances, entire fields are poorly drained or only partially drained fields upon which the farmer expends each year as much labor, seed, and fertilizer as he does upon his well drained land, but on which crop returns are generally limited and frequently fail completely. The cost of farming this poorly drained land is just as great, and frequently is greater, than the cost of farming well-drained land, while the limited crop yield obtained materially increases the average cost of production for the farm. It seems

desirable therefore to call to the attention of the farmer the advantages to be gained by thorough drainage of the land upon which he is earning his living, and to advocate that needed drainage improvements be made even under present depressed conditions.

Another phase of drainage work that is always in need of attention is that of ditch maintenance. Systematic annual maintenance is, as a general rule, indispensable if a drainage ditch is to continue to function efficiently. Such work should be urged. Some state drainage laws make little or no provision for the maintenance of drainage improvements after they are constructed. Studies should be made to determine the most effective way to amend such laws.

Another pressing need at the present time is the rehabilitation of drainage enterprises that have encountered financial difficulties. In planning such rehabilitation, provision should be made to correct all original causes of failure. The plan of refinancing must be based upon the probable income to be derived from the land. It is from these returns that the investors in the enterprise, both the landowners and the bondholders, must secure repayment. In connection with this work it is believed that a study of drainage legislation with a view of outlining amendments to existing laws covering procedure for refinancing and reorganizing drainage districts would prove valuable.

It is the hope of the Bureau of Agricultural Engineering that these and similar investigations can be undertaken by the Division of Drainage as funds are made available.